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ACCOUNT

OF

IMPROVEMENTS IN CHRONOMETERS,

MADE BY

MR. JOHN SWEETMAN EIFFE;

FOR WHICH A REWARD WAS GRANTED TO HIM BY THE LORDS COMMISSIONERS OF THE ADMIRALTY.

WITH AN APPENDIX,

CONTAINING

MR. ROBERT MOLYNEUX'S SPECIFICATION OF A PATENT FOR IMPROVEMENTS IN CHRONOMETERS.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF THE ADMIRALTY.

LONDON:

PRINTED BY PALMER AND CLAYTON, CRANE-COURT, FLEET-STREET;

AND SOLD BY JOHN MURRAY, ALBEMARLE-STREET.

M.DCCC.XLII.

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INTRODUCTION.

In the winter of 1835, Mr. Eiffe informed me that he had invented arrangements for correcting one of the errors to which the best chronometers are liable (the losing rate at extreme temperatures, whether of cold or of heat, when the compensation is adjusted so as accurately to counteract the effects of variation of warmth near mean temperature); and he communicated to me (in strict confidence) two constructions which he proposed to use for that purpose. These were the same as those represented respectively in figures 1 and 2, and in figure 11, of the plates attached to the following account. I had no hesitation in giving my opinion that, whatever unforeseen practical difficulties might be found in the actual introduction of those constructions into chronometers, the principle was correct, and admitted of being carried so far as actually to reverse the error, causing the chronometers to gain at extreme temperatures instead of losing, as is the case with all common chronometers; and, therefore, that the adjustment for equalization of rates throughout would become a question of mere manual dexterity. With my consent, therefore, Mr. Eiffe solicited of the Lords Commissioners of the Admiralty, authority for the trial of two chronometers at the Royal Observatory, with special reference to the steadiness of their rates at extreme temperatures. Accordingly, two chronometers containing Mr. Eiffe's improvements (marked Eiffe 3 and Eiffe 4) were tried at the Royal Observatory in juxta-position with two good Government chronometers (Earnshaw 543 and Earnshaw 819) from 1836, February 27, to June 25. In the colder season, they were exposed to the open air; in the warmer season they were heated by a fire; in the intermediate temperatures they were placed as usual in a room. The circumstances of the season were not favourable for the obtaining of extreme temperatures; nevertheless I was fully enabled to express a most favourable opinion on the success of the application of the principle. My Report, addressed to the Lords Commissioners of the Admiralty, is dated 1836, June 29.

Mr. Eiffe was, as I have understood, authorized by the Board of Admiralty to construct several chronometers for their use on the same principles. I believe, however, that no such chronometers were constructed. Nor can I give any explanation of the long silence of Mr. Eiffe in reference to the claims for reward which, I believe, he had at first urged.

In the beginning of January 1840, I learned that Mr. Eiffe had addressed a memorial to the Board of Admiralty regarding his claims for reward. About the same time (or perhaps earlier), I was informed by Mr. R. Molyneux that he had invented a construction for the same purpose as Mr. Eiffe's; and upon his explaining to me the general principle, I recognised it as being identical (in every important point) with one of Mr. Eiffe's invention. The terms under which I had acquired a knowledge of Mr. Eiffe's construction did not permit me to acquaint Mr. Molyneux that a similar improvement had already been invented. Mr. Molyneux informed me that he intended to take a patent for his invention: which intention was communicated by me to the Board of Admiralty, in correspondence on the subject of Mr. Eiffe's claims. I believe, however, that the principal officers of the Admiralty had already been made aware of Mr. Molyneux's design.

Two chronometers made by Mr. Molyneux (Molyneux and Sons 1839, and R. and H. Molyneux 2144), which, as I understood, were fitted up on Mr. Molyneux's plan, were placed at Greenwich on the annual trial for purchase of chronometers by the Government, from 1840, January 18, to August 15, and were, during that time, exposed to extreme temperatures of heat and cold. Both preserved a great steadiness of rate; the former, notwithstanding the severity of its trial (to which none of the competing chronometers were subjected), keeping a more uniform rate than any other of the chronometers then on trial.

About the end of 1840, both Mr. Eiffe and Mr. Molyneux addressed memorials to the Board of Admiralty, claiming rewards for their improvements. These, together with the memorial of another maker, were referred by the Lords Commissioners of the Admiralty to the President and Council of the Royal Society, for report upon the novelty and general merits of the improvements, and on their relative value as compared with those of Arnold and Earnshaw, to whom a public reward was granted. The Council of the Royal Society appointed a committee (of which I was a member), to examine in detail the mechanical constructions, and to report on the whole question: the whole of the correspondence bearing upon the matter was laid before them. A Report was agreed on by the committee, and was adopted by the President and Council of the Royal Society, to the general effect, that a public reward was due to Mr. Eiffe (on the usual condition of complete publication of his invention), and that no other person was entitled to reward. The reasons for these recommendations were stated in the Report; it is sufficient to mention here, that the circumstance of Mr. Molyneux having taken a patent was taken into account.

In conformity with the tenor of this recommendation, a reward of £300 was granted by the Lords Commissioners of the Admiralty to Mr. Eiffe.

The publication of Mr. Eiffe's account of his inventions (as laid before the committee of the Royal Society), has been for some time delayed, under the idea that Mr. Eiffe

intended to prepare a more detailed account of experiments of various kinds, bearing upon different points in the construction of chronometers. Having, however, ascertained that no such account was prepared, I represented officially to the Lords Commissioners of the Admiralty, the advantage of immediately publishing the account laid by Mr. Eiffe before the committee of the Royal Society. I also, upon my responsibility, suggested the propriety (under the circumstances above described) of printing with it the specification of Mr. Molyneux's patent, having previously received Mr. Molyneux's consent to that step. Their Lordships were pleased to assent to both these proposals; and the present account of Mr. Eiffe's inventions, with the specification of Mr. Molyneux's patent, are accordingly now published at the expense of the Admiralty.

I have only to add, that a considerable quantity of matter, irrelevant to the subject of the improvements in chronometers, has been struck out of Mr. Eiffe's account, at my discretion.

G. B. AIRY.

Royal Observatory, Greenwich,
1842, *March* 22.

IMPROVEMENTS IN CHRONOMETERS,

&c.

In the year 1818, Mr. W. J. Frodsham addressed a letter to Mr. Croker, the then Secretary of the Admiralty, wherein he represented the important advantages that would result to chronometer-makers by a public competition, and to chronometrical science in general, should the Lords of the Admiralty deem it worthy of their Lordships' consideration.

In the year 1821, the Lords of the Admiralty commanded that a public trial should commence. Three premiums were presented, of proportionate amount, to the three chronometers most distinguished for their superior performance at the close of the year. Another, and consecutive yearly trials, succeeded. By those trials one great advantage was obtained, and that in the earliest year of the annual trials: each depositor discovered that a former negligent mode of construction and adaptation must be discontinued, to enable him to hope for any participation in those rewards. Subsequently the chronometer-makers, almost simultaneously, brought forward, on the second and third years of the trials, chronometers far superior to those that had appeared on the commencement of the experiment, and, no doubt, gave assurance to their Lordships of the Admiralty, that still greater improvements would succeed. For many years the public trials succeeded one another, but there was no demonstration of improvement. At length their Lordships determined on rescinding the original order; and, after the 13th year, the public trials became extinct.

Many years ago the writer of these papers was delighted with the excellent performance of the few chronometers which obtained the premiums; the going of some, in particular, was admirable; but in the general satisfaction their good going produced, one prevailing desideratum always existed: a constant unvarying tendency *to lose in the extremes of temperature.* Further on will be remarked an apparent discrepancy and contradiction to this principle, in the evidence of some chronometers on those trials, as showing an exemption from that error. My attention was called to chronometers of undisputed character, whose regular attention to the changes of temperature, even in their excellence, paradoxical though it may seem, was as regular as the changes of the thermometer itself. They showed, certainly, the correct judgment of the chronometer-maker, who so nicely balanced the errors of the extremes of heat and cold, as compared to the always prevailing plus or gaining rate in the intermediate actions of temperature. But those errors, however trifling in two instances, prevailed universally and without a single exception in all, even in the two instances just alluded to (the good performance of which has made them famous, without conferring any benefit on science); exciting the admiration of chronometer-makers, and creating regret, for the most part, in the minds of those whose names they bear, that no model was constructed, no correct feature introduced, whereby several chronometers could be constructed.

From several experiments I have from time to time made on chronometers, I feel no hesitation in asserting, that the performance of those two chronometers was the result of a combination of errors, one correcting the other. That an extraordinary harmony of accident existed, and an unobstructing mechanical excellence in the wheel-work, as connected with the momentum of the balance, there can be little doubt; making, on the whole, in their wonderful union of purpose, two productive instances, out of more than one thousand chronometers of very superior performance. Yet it is vain to refer to any advocacy of the very superior performance of those* two chronometers in the changes of temperature, wonderful as is the printed record; the same old, irritating, losing error, in the extremes of temperature, is manifest in both, and both are monitory instances, in their respective inclinations to the fundamental law, of the want of perfect harmony between the pendulum-spring and the balance, and of the moreover absolute losing tendency always in the extremes of temperature: those two chronometers, therefore, lost in the extremes. No chronometer of distinguished character, since the commencement of the government trials, ever showed a contrary tendency; that is to say, ever gained in the extremes: to this there can be no contradiction.

It is a gratification to the writer of these papers, that the best chronometer that ever appeared at the Royal Observatory, up to the year 1829, was a chronometer, *z z z*, Eiffe. That chronometer, for a period of five months, from the 1st of August, 1828, to the end of the year, made the extraordinary small error of *eighteen hundredth parts of a second*, from its mean daily rate. The range of the thermometer during that period was from 72°, and descended, in one instance, to 38°: that rate was without parallel; it has not been surpassed since. Yet, however gratifying the circumstance, it only brought a regret to my mind, on account of the monition it gave by its rate, on a cold day in November, of the result that would be produced by a continuation of severe weather. True to that monition, in the cold of January the chronometer made four times the error that it had made in the preceding five months.

My mind was confirmed on the further prosecution of experiments I had made in framing an auxiliary power early in 1828, calculated to destroy that losing tendency. One of those experiments showed successful results, and only required to be repeated, to prove that such an auxiliary power would be an introduction of general utility. The success of that experiment is proved by reference to a letter I had the honour of addressing to the Astronomer Royal, in the beginning of January 1841. The experiment took place on the public trial at the Royal Observatory, in the year 1828-1829, under the affixed name of B.

I took many opportunities, at that early period, of proving my experiments, and of seeking out the best available modification, knowing that, sooner or later, I owed it to myself to claim the originality of the invention. In my future experiments I was resolved to try the relative advantages of all. My success has been various in those experiments as to preference; and the most irritating obstacles I had to contend with were faults inherent in the construction of the chronometer itself, entirely independent of the auxiliary power; but as those were in the nature of things, and common to all chronometers, as well as chronometer-makers, working in the known school, I could not be surprised that I should have to retain them in the new.

The experiments on two chronometers, No. 3 and No. 4, tried by the Astronomer Royal, Mr. Airy, in the year 1836, prove publicly the certain usefulness of my inventions. The Astronomer Royal declared, in his Report to my Lords Commissioners of the Admiralty, that

* French, in 1825; Dent, in 1829.

those chronometers were "the best he had ever tried." The successful issue of these experiments became known, of course, to many gentlemen connected with the Admiralty.

Having proved * that I had surmounted the error, to lay before the Royal Society papers and drawings descriptive of the modifications or modification I most prefer, is the main object. To describe each, and to point out their advantages in relationship with one another, will, of course, be most respectfully committed to writing. That all are equal singly to correct the error in extremes of temperature, and to give to any chronometer an advantage superior to what it before possessed, I can give an answer in the affirmative, unreservedly.

The modification I prefer must be, at present, hypothetically advanced. It would take much time to be able to insist on the comparative degrees of merit, and it would be a hasty assumption on my part even to attempt a classification. To those gentlemen connected with the same mechanical branch as myself, I leave, for future years, the examination in practice of the several modifications; and I shall be most happy to hear their reports at some distant period. I only claim the merit of introducing the principle. Notwithstanding, I will offer, at the close, and in the descriptions of the several modifications, my opinion as to which I would wish to call general attention.

But before the description of the figures now about to be laid before the Royal Society, it would be highly important to inform that body of a matured result of the several experiments I have made upon the chronometer, as used up to this period.

The advantages introduced by the auxiliary power can only be understood, and their usefulness appreciated, by the comparative importance of the old system.

I will suppose, therefore, that several new † chronometers are made isochronous; for without a very near approach to such character, the machine possesses not a most important, a most essential quality. The error which would be shown by those several chronometers, in their mean daily rates, and in comparisons in mean temperatures from ‡ 25° to 100° Fahrenheit, would be from 4 to 15 seconds: beyond those points of the thermometer, the error of chronometers is of much more considerable magnitude. I have rarely found the error less than five seconds; and in making this statement I am prepared for all contradiction, and fear none from those tolerably efficient in the business I profess. My conclusions have come from no hasty inquiry, but from experiments tried on chronometers of the most valuable kind; not the conclusions of a night of cold, always flattering and deceiving, partial and untrue. Chronometers which seemed immovable in their rates, and the extreme variation of which, one day with another, for months had been scarcely one second, have, when exposed to an excess of temperature, sometimes wandered as much as 10 or 15 seconds in 24 hours, not at once, but gradually. In such severe temperatures the changing daily rates is very ridiculous. Chronometers which, in the comfortable atmosphere of a room, in a temperature from 55° to 70°, had been the models

* Through the experiments at the Royal Observatory, as well as those conducted by Mr. Airy.

† Or old, it matters not; though the old should be preferred for experiment.

‡ It may be asked why I make 25° the point of the greatest cold, when chronometers in northern latitudes must encounter an excess of greater intensity. The reply is, that a lower point of the thermometer is rarely met with in this country; and, as a point for experimental purposes, 25° is so severe that all chronometers, on the common principle, will err from three to five seconds on their rates, at that point, when placed in comparison with the rates denoted at 55° (provided always, the chronometers are balanced at the other extreme of temperature). I beg to be distinctly understood, that it is not meant to give any consideration to the experiment of a few hours; the experiment should be repeated in the cold consecutively.

of excellence, afterwards wandered from 70° to 100°, in sums of 2, 4, 6, and 8 seconds: as regular in their irregular rates, while the thermometer itself changed through the intervening parts of its scale, as they were before immovable during the thermometer's course between 55° and 70°. Now, if these* results are deductions from the characters of good† chronometers, commonly called, and nicely balanced adjustments, how wretched must have been the state of those under the hands of the observant experimentalist, when, instead of being balanced between the extremes, the error should have been designedly placed to the account of the heat or the cold, and an equality of rate sought by rendering the performance of the chronometers, in the intermediate temperature, equal with one of the extremes.

First take the example of what is commonly called a good chronometer, with an isochronal pendulum-spring, and which does not possess the improvements in consideration, the error of which in the extremes would be evenly balanced, and going to mean Greenwich time in mean temperatures, and the greatest loss in the extremes should be the minimum of error allowed, four seconds; it would stand thus:—

Excess of cold	— 4″·0 at 25°
Mean temperature	0 ·0 at 55
Excess of heat	— 4 ·0 at 100

Take for the second example, the principle of adjusting the same chronometer to suit certain latitudes, or for navigation in the regions of high temperature:—

Excess of heat	0″·0
Mean temperature	0 ·0
Excess of cold	—8 ·0

Here we find the error carried to one side. The chronometer has come home with an excellent character from the southern region. The following winter the chronometer is found in a northern expedition. It had left England with a fine character, a mean time rate, and a very skilful commander to the ship to which it belonged. Confident in its extraordinary merits, with commands, perhaps, from the Admiralty to lay down or to confirm northern longitudes, the captain returns ultimately to England, greatly disappointed; and what is of serious importance, perhaps, after having come to some objectionable conclusions with reference to previously correct longitudes.

Let it not be supposed that in the description given in the last paragraph, of that which may be considered a good chronometer on the old principle, I am ignorant of a method to produce a nearer approximation of rate in those given temperatures. That subject, and its *unworthy ingenuity*, shall shortly be attended to. That the method of obtaining it has inflicted the greatest imaginable injury on chronometer-making in general, there can be no doubt. There is certainly great reason for an imperfect state of spring and a non-existence of the isochronal principle, with reference to the correction of one error, an important‡ one; it is however, turned to another, the adjustment of rates in the various changes of temperature. Thus the assumed excellence is truly artificial; and the inconsiderate and always incomplete possession of those hollow advantages are of slender value, after all, on account of the careless regard for consequences which must shortly ensue by the sacrifice of the grand principle, the

* The error in the cold is also to be included in the same proportion.

† Chronometers fast in the short vibrations cannot be called chronometers; the maker who trusts much in such must prepare himself for disappointment.

‡ The positions.

isochronal property of the pendulum-spring. That principle almost gives the chronometer its name.

The pocket chronometer as universally constructed, when isochronal, that is to say, when the slender spring affixed to the axis of the balance denotes, through the agency of the seconds' hand, equal particles of time in different arcs of vibration, is constituted in error and with feeble capability. Independent of the difficulties it has to contend with, on account of its size, there are many other opposing circumstances. Independent of the oil, always necessary, there are agencies inseparable from its construction that have hitherto placed it in a somewhat false position. There are many who attribute a wandering from its rate to causes quite different from the true one, and to the circumstance of the smallness of its diameter; they deduce its errors from many other causes, some real, some imaginary. That it requires a practised hand, and very mature judgment, to make a good chronometer for the pocket, all practical men are unanimous. That, occasionally, good pocket as well as good box machines have been produced (on this false principle of adjustment) is an unimportant assumption; but there can be no hesitation in stating, that almost two-thirds of their error and unsteadiness of rate are to be attributed to the very defective state of the compensation.

The error of the pocket chronometer in heat and cold, and with an isochronal spring, is from 7 to 20 seconds. Much depends upon the temper of the spring. The error of chronometers with soft springs at 100° Fahrenheit is incredible.

Their wandering from their rates is to be mainly attributed to a want of isochronal character. If the little machine is isochronal, and its mechanical freedom carefully attended to, it will give a limited satisfaction; but it generally happens that chronometer-makers themselves regard pocket chronometers in a slight degree: it is a great mistake; skilful makers think not so. It generally happens that the little machine is either fast or slow in the long and short vibrations; is not isochronal.

A pocket chronometer which is slow in the short vibrations, though, if mechanically well arranged, it may give moderate satisfaction, will be very unsteady in its daily rate, one day with another. This observation will apply to it in any temperature, however remote from the extremes. Besides the daily irregularity caused by a want of isochronal character (for, considering the delicacy of the little machine, compared with the strong, substantial, large chronometer, it is more sensitive in that respect); still that is not the greatest difficulty it has to encounter. The pocket chronometer, almost universally, has less length of spring,* in proportion, affixed to the axis of the balance than the large machine. In the winding and unwinding of the spring, in the arcs of vibration, its centripetal action is more violent, and consequently the reverse action also; it follows, therefore, in its expansive or centrifugal action, it passes over a greater part of the diameter of the area of its balance than the spring in the box chronometer, which is longer and has more turns:† the consequence is, that the spring is more powerfully acted upon than that of the large machine. A pocket chronometer of this description will commonly err from 8 to 20 seconds in the extremes of temperature. Chronometer-makers, in general, place all the error to the side of the cold; they know how much more *imprudent* it would be to transfer the amount of error to the heat. Thus, doubling the error, such chronometers exposed to a long cold of several days, at 25° Fah., would lose from 16 to 40 seconds in 24 hours; but dividing the error is, of course, a matter of consideration.

* Commonly called the pendulum-spring.

† The spring is well known to be cylindrical.

Now, it will be necessary to describe the pocket chronometer when fast in the short vibrations; a method always adopted by chronometer-makers of any eminence, who study, amongst conflicting difficulties, the main object, that of giving general satisfaction, be it more or less. Prudence marks out this line of conduct, and it presents, certainly, many advantages, some real, some imaginary;* it has many dangers, and the one great, positive, and fatal tendency: that, however, is well understood, and must, of course, be admitted.

The skilful chronometer-maker prepares his balance-spring in such a manner, as that the pocket machine will gain from 7 to 14 or 15 seconds in 24 hours, at the arc of vibration of $\frac{8}{10}$ of a circle at its axis. We must suppose that the balance, when it denotes what are commonly called the long vibrations, is vibrating $1\frac{1}{4}$ of a circle, or $1\frac{1}{5}$,† and the chronometer, at the long vibrations, going very near to mean time. This chronometer can now be adjusted in heat and cold, and the results will prove very satisfactory. The error in extremes of temperature, which under former circumstances of the state of the spring had been enormous, even in the case of isochronal vibrations at the just mentioned arcs, will become considerably reduced, particularly towards the highest number of 15 seconds; though at no point is the cure perfect. Still it has been gratifying to find that, at 100° Fahrenheit, impressions were comparatively slight; therefore, from 25° to 100°, the error will become considerably reduced: the good going of the little machine in positions, will also be manifest, and all will seem well. This is a short, analytical description, of the pocket chronometer, as hitherto known in its best state.

But the obtruding evil connected with this flattering position, is the positive determination to gain on its mean time rate. This must take place sooner or later; it may commence at once, or in six months; gradually, or all at once. Men of right thinking minds must regard such a chronometer as a mere cheat. ‡

It will now be necessary to describe the character of the box chronometer. The placing any remarks upon it, in this part of these papers, will be attributed to a desire to have them as near to the descriptions of the auxiliary power as possible. Though it has been found necessary to enter a little into the merits and demerits of the pocket chronometer; though any of the modifications of the new principle will be found, when generally used, to bring very great advantage to the box chronometer; they will now, for the first time, render pocket chronometers useful for particular navigation. Before, they were almost useless: their errors in extremes of temperature being nearly one half greater than those of the box chronometers, for reasons already mentioned.

The box chronometer has not been improved during the last half century. By comparison of chronometers made as far back as that time, and by reference to their rates, no

* That surely must be considered an imaginary advantage, which has existence only for a few months. When friction increases as the oil thickens, a new rate gradually presents itself.

† The latter is much to be preferred, as in such state the escapement is less liable to trip, and the vibrations much better for determining the positions.

‡ I must again repeat, that I am well aware that a chronometer which possesses an isochronal spring may wander from its rate; that is only an uncertainty, at most; this is a certainty.

The advantage a chronometer possesses with a pendulum-spring designedly left not isochronal, is that, on account of the vibrations of the balance being less when not in a recumbent position, the machine goes faster in the short vibrations, which bears proportion to the otherwise slow rate, on account of the increased friction when not placed horizontally.

improvement in the art is discovered at the present period. There may be more glitter, but nothing useful has been introduced: we have been, in most points, docile imitators.*

Several industrious men have tried in vain to improve the constitution of the escapement. They simply imagined that some of the errors which the auxiliary power will remove, were caused by an imperfect escapement. They have toiled in vain: it would be difficult to improve that simple, though, at first sight, complex modification. Its simple character is its greatest security: to depart a little from that simplicity, would be to produce confusion and create friction. To make still less the slight degree of friction which takes place in its action, (it has undergone no change since the time of Earnshaw), is alone advisable.

The box chronometer, when it has an isochronal spring of 10 or 11 turns, will give great satisfaction. Isochronal springs are always sought for by chronometer-makers who value their reputation. The good chronometer, with an isochronal spring, will perform for many years with scarcely any variation from its rate in similar temperatures. It will be curious, as well as amusing to the Royal Society, to be informed that all the chronometers which were distinguished at the Royal Observatory for the slight impression made on them by the heat and cold, comparatively certainly, were machines not isochronal. Each depositor imagined the secret his own. The chronometers that were found to be a few places from the first, were really the best machines, except in two or three instances. Had the public trials lasted eighteen months, when oil began to thicken, there would then have been a change of places. References to rates will show how many of those fortunate few, through the circumstance of their being made fast in the short vibrations, were on the extreme of their plus rates, at the close of each trial. The year of trial ending, relieved a growing anxiety. I must confess that I myself followed the same plan, in a moderate degree. I generally made the chronometers I intended for Greenwich, in such a manner, as that they should gain in the short vibrations about 4 or 5 seconds in 24 hours. I knew that it was not sufficient to procure a very near † approximation of rate on the changes of temperature; but I thought it imprudent to act otherwise, under all circumstances. To make chronometers for the public trials, and to choose from a large number of those which were never intended for them, was always considered, nevertheless, to bring very different results. A box chronometer, to make a near and pretty uniform rate, at Fahrenheit 30°, 55°, 80°, should be from 15 to 20 seconds in 24 hours faster in the short than in the long vibrations. A dangerous experiment, yet such has been tried: fatal to some, fortunate for one or two.

With respect to the laminæ of the balance, which, when cut through, as seen in the figures, compose the arcs of its circle, many experiments have been tried. Mr. W. J. Frodsham has devoted much attention to the proper proportions necessary to be ‡ observed in preparing

* The late Mr. Arnold distinguished himself by an indefatigable industry. I have seen some beautiful work by Mr. Mudge and Mr. Larcum Kendall.

† Some used oil that would freeze, which by greatly reducing the vibrations of the balance on its axis, in cold 25°, 28°, gave a very flattering demonstration. I had privately made those experiments, but soon laid all aside, to introduce my grand principle, which would remove all those vain artifices for ever. To find the time the chronometer shows in the short vibrations, the curious has only to lessen the power of the main-spring.

‡ I have tried some experiments, but have not been equally successful, and often found contradictory results.

the substance of the circle. I have had the pleasure of receiving copies of some very extraordinary and well-authenticated rates of chronometers made by him. *

I will now conclude this introduction, and will then commence the descriptions of the various diagrams, pointing out, as far as I am able, the advantages and comparative disadvantages of each. I have had no other object in view, but an endeavour, to the best of my humble ability, to explain the reasons why it should be considered necessary to remove, by some means, a prevailing and always prevailing error. If I venture to declare that any modification of the auxiliary power in the annexed drawings has the property of rendering the state of the chronometer far superior to what it has been hitherto, and that the new † constitution of balance presents in its simple form almost all that can be desired, I hope it will be considered I have done some service.

* Mr. W. J. Frodsham did me the honour of writing a letter, with permission to lay it before the Admiralty, commendatory of my improvement referred to in these papers. "I have no doubt," writes Mr. Frodsham, "from your description, that it is a great improvement on the old principle."

† The compensating diameter bar, having a spherical action.

DESCRIPTION

OF

THE FIGURES OF THE SEVERAL MODIFICATIONS OF EIFFE'S INVENTION, TO CORRECT THE ERROR OF CHRONOMETERS IN EXTREMES OF TEMPERATURE.

Figure 1,

Represents the compensation* balance of a chronometer, as generally† used when the new invention was introduced, with its weights and screws.

In the area of its circumference, and attached to the diameter bar, *a*, which is of steel, are attached the parts of the new invention, in its original state. To the mechanical eye it presents a rude‡ diagram; but I beg to observe that it was merely an experiment.

a points out the bar uniting the arcs of the quadrant of the circle; *c c* are sliding weights of brass (sometimes they are used of different shapes), grooved like a pulley, and secured by a brass cap and its steel screw, which presses upon the outside rim of the arm, or quadrant, as in the figure: *d d*, represent the timing screws, the object of which is well§ known: *l l* are abutments, to strengthen the arcs of the quadrants: these were introduced by me.

Invention.—The small arm, *f*, which is affixed to the bar, *a*, by means of a screw, as seen in the diagram, was the first step taken in the formation of my improvement. The screw is so confined, as to let the arm, *f*, have free action up and down, commonly called end-shake; *g* is a cylindrical piece, screwed on the arm for the purpose of obtaining the proper correction of time required in the adjustment for which it is intended: *h* represents a spring attached to the diameter bar; it has a twofold object: first, to counteract the otherwise vacillating motion of the arm; secondly, by means of the screw, *i*, which passes through its tail, and presses against the tail of the arm, *f*, to preserve the equilibrium at the other end: *e* represents the introduced‖ compensation arm attached to the diameter bar, *a*, the known pro-

* I have endeavoured to explain, as plainly as possible, all the parts of the balance of the chronometer. Much that is written here about the component parts of it is known already, but a repetition may not be found disagreeable to those who are well acquainted with those parts; to those not so well informed, it will be preparatory to the description of the proposed improvement.

† In fig. 24 will be seen the balance cut open near its diameter, at *m m*.

‡ Rude as it is, the chronometer to which it was applied went better in 1828, in the various changes of temperature at the Royal Observatory, than any other chronometer. There were 70 or 80 on the public trial.

§ The above description (divested of the auxiliary improvement) is the form of the balance I most prefer for common purposes, for chronometers hitherto in use.

‖ The above diagram of the balance itself was the form I was instructed to use, but weights of a square form were common. Innumerable old chronometers, made about the year 1825, will prove this statement.

perty of which will act upon the extremity of the arm, *f*: *k* is a large screw affixed to the arm to equipoise the balance on its axis.

Explanation.—By directing the attention to the arm, *f*, with its cylindrical body, *g*, which by a tap through its centre, is made to move to and from the screw which affixes the arm itself, it would be found that, on account of the assistance it receives from the slender spring, *h*, at one end, and the small screw, *i*, passing through the spring's tail at the other, the whole is perfectly steady, and only capable of centripetal power by pressure. That pressure is to come from the compensation arm, *e e*. As seen in the diagram, the chronometer is in a temperature of 55°. The error of the two extremes is put to the point of the cold only, that is to say, the chronometer has been made to go the same in the cold and temperate points: as the temperature verges towards the other excess, the arm, *e e*, will advance upon the point of the arm, *f*, and so prevents, by propelling it to the centre, the chronometer from losing considerably* in the heat. Thus, the chronometer can be made to perform with a uniform rate in all the changes of temperature until it approaches 100°, at which point it suffers considerably, and can with difficulty be governed with the auxiliary power.†

Figure 2,

Is a more mechanical modification of the same invention. It will be observed at once that the object is the same as in figure 1. It represents a small balance placed in the area of the larger one, and affixed to the diameter bar in the same manner. The arms, *e e*, act in the same manner; the weights, *f f*, act similarly to the cylindrical weight, *g*, in figure 1; the arms which bear the weights, *f f*, at the parts, *g g*, have the brass portion of the circumference cut away, in order to cause that portion of the arm on which the weight is fixed to yield to the pressure of the adjacent arms, *e e;* it will moreover be seen, with the assistance of the little screws, *h h*, that the same object is attained as by the screw, *i*, in figure 1.

Figure 3.

In this figure, we see a balance properly intended for the auxiliary power, the subject of these papers. The other figures 1 and 2 represented balances which were not originally intended for the application; and which, being deprived of nearly one-half of their circles, were found to be incapable,‡ with what remained, of producing the desired effect with such an application as is seen in this figure. Now here with a balance designed for the object, and an

* A chronometer in this state without the auxiliary power would lose from 7 to 15 seconds between 95° and 100°. Over 100° Fah. the oil suffers very much.

† The chronometer without the auxiliary power, and when made to perform the same rate in the cold and temperate points, will begin to lose from 2 to 3 seconds at 70°, gradually increasing in the error up to 100°. How impotent, therefore, when unassisted by the auxiliary power.

‡ In the year 1831, I applied this figure to the chronometer, No. 3 (the chronometer was tried with another modification in 1835-1836); the elastic arm was affixed close to the inner rim of the balance; on account of the weights it could only describe 60° at the centre. It was found to be insufficient. It was subsequently removed, being confined for space on account of the weights, which advanced forward over the rim, and not as seen in figure 3, but as seen in figure 1 and 2, with the trifling difference of being square, as were then generally used. The holes and marks prepared for that experiment can be seen on the chronometer, which has been in her Majesty's service since 1836. The chronometer at present possesses that of figure 20. Mr. Airy, the present Astronomer Royal, tried experiments on it in 1836. In the previous year, 1835, its rate at the Royal Observatory was not different in the changes of temperature.

auxiliary arc of near 120°, instead* of 55°, there is no difficulty. The weights for the heat and cold, and the screws for timing, are here shown, as in fig. 1 and 2. The weights are so prepared, as to work entirely on the periphery of the circle of the balance, lest it should be necessary to move them, to obtain the general compensation, towards the circular auxiliary arms in that adjustment: *m m* is the opening in the circumference, to give the arms of the balance action in the compensation: *f f* are the points where the auxiliary pieces are affixed; the interstices at the time-screw show where the elastic character is given to the auxiliary † arc: *h h* are the larger screws, used to obtain that proportion of time necessary in the adjustment: *g g* are the screws, the points of which are acted upon at the proper period of temperature, by the arcs or arms of the balance. The little screws adjacent to the larger ones, are for very ‡ minute corrections, &c. &c.

Figure 4,

Is a perspective view of the exterior of fig. 3. The altitude of the balance is seen in this figure: the oblong square cut, which passes through the weight, *c*, shows how the chronometer-maker can obtain that true proportion which is to determine the heat and cold: *k* points out a narrow deep groove, cut to the depth of half the substance of the brass, which united to the steel forms the circle, *b*, of the balance; *n*, and its small holes are for arranging the minute portions of time, as before mentioned: *i i* the profile of the little screws seen in the plan, fig. 3.

Figure 5,

Is an interior perspective view of fig. 3: *a a* show the substance and the proportion for the diameter-bar: *o* shows an exceedingly thin cut through the rim of the balance; it gives elasticity to it, and gentle pressure to the time-screws, when worked by the power of the screw-driver.

Figure 6,

Is another modification intended for the old chronometers; on account of the shortness of the arcs of the circle, the centripetal action of the cylindrical piece, *g*, is acted upon in the same manner as in the original, fig. 1. The cylindrical piece is made a little eccentric from its tap-hole, in order to obtain the distance required from the point of the compensation piece, *e*: *f f* the pieces, or arms, which bear the cylindrical pieces, *g g*; they are of steel, and are made elastic at pleasure. The rest of the figure is to be seen in the description of fig. 1.

Figure 7,

Is very similar to fig. 3, as regards the object to be obtained; and, indeed, all the figures, and all other figures, must bear similitude to fig. 1 in that respect. The mechanical ingenuity then only attracts attention. There is only one object centripetal. *c c c c* are the weights; the larger ones are seen at the extreme points of the periphery: their

* An arc of 55° was applied to No. 3, Eiffe, in 1831.

† The best and most useful (for new chronometers) of all the modifications can be made from this figure, by not removing those portions of the arcs of circle or ring from which the auxiliary pieces are formed, and which would each make an angle at the centre of about 55°. Guards, to protect the balance from injury, could then be formed, as in fig. 7, but with much less difficulty.

‡ An important assistant to obtain the minute particles of time. This will be found useful by chronometer-makers.

object is threefold; to obtain the heat and cold, proper, assisted by the smaller weights, *c c*; to carry the propelling screws, *g g*, which act against the extremities of the arms, *e e*; and to be used as guards* to protect the balance from injury; *k k* are the guard screws, *d d* are the time screws. The rest of the figure is described in figure 3.

Figure 8,

Is the exterior perspective view of figure 7, showing altitude, and scarcely dissimilar from perspective figure 4. At the weight *c*, can be seen by the pins the object of the narrow deep groove on the periphery of the balance; they describe steady pins.

Figure 9,

Is the interior perspective view, &c., &c.

Figure 10,

Is a simple modification. Passing by the already repeated description of the balance, its weights and screws, we will come at once to the auxiliary pieces, affixed in the area of the balance by the screws, *g g*: those arms are compounds of brass and steel, carrying the screws, *e e*. An oblong square hole is cut through the rim of the balance. *h h* are eccentric screws to adjust the arms in a direct line from the centre, and perpendicular [parallel] to one another; but it is not absolutely important.

EXPLANATION.—To those to whom some, if not all the other figures seemed to present perplexity, this figure points out a beautiful direction to the object sought; in it we see a most simple demonstration, easily to be conceived. When we consider that chronometers make a faster rate in mean temperature, one glance at the figure before us will show that these auxiliary pieces will give the balance more active vibration in excesses† of temperature, on account of the centripetal character of these compensation arms in those excesses, their action being orbicular.

Figure 11,

Is an improved modification of fig. 20. There is an application affixed to the side of the strong bar, or cock, as it is commonly called; the altitude of which, from the plane of the chronometer-frame, is about $\frac{1}{4}$ of an inch, but as seen in the profile, fig. 12, is much higher. The figure is composed of a compensation-bar, constructed from the substance of the quadrangular figure 26; at its extremity, and about $\frac{1}{10}$ of an inch from the point of suspension,‡ it acts through the agency of the screw, *f*, upon the pendulum-spring, *m*, of the balance: *e*§ is the lamina for compensation: *g* the screw which secures it to the cock: *h* the stud through which the screw, *i*, passes: *k* the point of the screw, *i*, which passes through a hole

* See the note to figure 3. There a more simple guard is proposed; more easily made; where the whole apparatus is made out of the circle or ring placed within the area of the balance.

† The draftsman has forgotten to insert a mechanical method of obtaining a right line, with attached pieces and lateral elevations with screws.

‡ Fig. 20 was applied to the chronometers No. 3 and No. 4, which were experimented on by the Astronomer Royal, Mr. Airy, in February 1836, and subsequent months.

§ This lamina should be made very thin, hardened, and tempered, and in substance, except at the part for the little screw, *f*, about $\frac{1}{100}$ of an inch.

in the elevated foot, where it is secured. Here is seen a double purpose: to prevent lateral motion, and to propel* the compensation-piece forward, or the reverse, if necessary. *f* is the little screw, through the agency of which the operation† is performed against the spring, *m*. The piece of brass, of knife-like form, with its screw, is the stud which supports the spring, *m*, to which it is secured by a pin, as seen in the figure.

Figure 12,

Is a profile view of fig. 11. The balance with its pendulum-spring, *m*, is seen in profile, and presents the appearance of that which is commonly used.

Remark.—It is necessary to write a few observations on these figures, 11 and 12. The modification was adopted in 1832 and 1833. Experiments had been made on it previously, in 1831, when it was invented. In 1834 they were attended with successful results; so much so, that two chronometers were placed on public trial in 1835, the year previous to the appointment of the Astronomer Royal, Mr. Airy, to the direction of the Observatory. The public trial of 1835 was slender (always was so, as regarded extremes of temperature), but the two chronometers, 3 and 4, showed better rates under the excitement of heat and cold, than *any chronometers* at the Observatory in that trial; or, to write more plainly, they showed not the vulgar tendency to lose in the extremes. The next year‡ Mr. Airy subjected them to severe actions of temperature. The Astronomer Royal's report is well known.

I have given more attention to this modification than to any other; for, though the results were not so satisfactory always as could be wished, the advantages to be obtained from a patient inquiry would be valuable, I felt persuaded, as prospective, and very much more so as retrospective. I frequently dwelt on the importance of an inquiry that regarded an improvement which might bring assistance to fine old tried chronometers on the old principle, most of which had their balances cut at right angles.§ Now, as all practical men know, there are more good old chronometers in the royal and merchant service, than all the chronometer-makers in England can hope to approach, by a united industry of twenty years: that those chronometers, when occasionally re-adjusted for heat and cold, should be so constituted in their balances, having their weights in different parts of the quadrangle, as not to admit of any application without endangering their excellence, would be an unpleasant consideration. Fig. 11, being an application to the spring‖ of the balance, settles that difficulty.

* The point, *k*, is strictly such; the tap is turned away, so as to leave a short small pivot, for greater convenience.

† This generally takes place about 55°, but there is no particular point of the thermometer with this figure, or any other figure; even of those to be applied to the balance. All *must depend* on the amount of error found in the extremes: if more, at 50°; if less, at 60°.

‡ Mr. Airy succeeded at the close of 1835.

§ The late Mr. C. J. Cope commonly did so, following Mr. Earnshaw's system; so also the late Mr. Molyneux, who with Mr. Cope were pupils of that distinguished man.

‖ The spring of No. 4, Eiffe, after eight years' service, did not suffer from the application of that delicate body, so very minute is the arc of motion made by it at the point of suspension.

Figure 13,

Is another modification for the same object. This is an excellent figure, and combines all the improved character of fig. 2, following the original fig. 1. The figure might safely be applied in some instances to the good old chronometers: *e* and *f* describe the principle. The arms, as seen in the diagram, are formed, as well as the foot, *e*, where the screw secures all to the diameter-bar, from one solid mass; a very important consideration (the adjusting screws alone excepted). A piece of steel, about $\frac{1}{16}$ of an inch in substance, is first prepared, with two strong arms, of which some idea can be formed from their appearance in the finished state: that body, with its arms of steel, is then put into the crucible, and the compound substance is prepared, as with the common balance: the whole is afterwards carefully finished, and elasticity obtained at the parts *f f*. The points of the adjusting screws are most worthy of attention: at those points, and formed from the compensation propelling bar, are inclined planes. They have this advantage: as the increasing temperature approaches 100°, the auxiliary power seems to require, as it propels, a more active character: this in itself is a demonstration of the want of elasticity in the spring,* and shows that these auxiliary arms and bars, or pieces, however slenderly made, are as defective as the arcs of the circle of the balance. The inclined planes, finally, appear there more as substances whereby to be able to form ingenious angular or arctical † figures, so as to obtain more centripetal action towards the point of 100° Fahrenheit, or the reverse of extreme cold.

Figure 14,

Is the perspective interior view of the last figure: the substance of the auxiliary affixed piece is plainly shown at *e e*.

Figure 15,

Is another modification of fig. 11. It is designed for those who make experiments in temperatures exceeding 100° Fahrenheit. It has an itinerary, or forward ‡ motion, combined with lateral pressure, as in fig. 11.

Figure 16,

Is an interior sectional view of fig. 17. At the point, *f*, is seen the small hole and exceedingly thin slit, for elasticity: at this point is placed the little screw, which is placed in close contact with the pendulum-spring, *m*, as in fig. 11.

Figure 17,

Is a rectangular modification of the same feature as fig. 15. This is also meant for those who are curious in experiments in excessive temperatures, and shows what can be done, rather than what the prudent would § do. This modification has still greater capabilities than fig. 15.

* Pendulum spring.

† I have tried a clumsy method of bringing (with reference to the balance) one auxiliary piece into action at 90°, following to support the other, which commenced operation at mean temperature.

‡ The draftsman has made it clumsy and strong.

§ There may be extreme cases, where such a figure might be required in practice, even for temperatures under 100°: I mean for chronometers (which are useful at mean temperatures) whose loss of time at those points of the thermometer will sometimes exceed 25 or 30 seconds in 24 hours. Those chronometers might show a very creditable rate, between 50° and 70° Fahrenheit; and when we consider that the greater part of the year is of such temperature, and rooms and other places for another portion, they might give general satisfaction.

Figure 18,

Is a similar modification to fig. 11 in the plan view, &c. &c.

Figure 19,

Is also similar: this modification has an index and scale, to take notes at intervals of experiments, and for reference after periods and lapse of years.

Figure 20.

In this figure is seen a rude imitation of the application tried by the Astronomer* Royal. It is secured with the screw, *g*, and steady pin: at the point, *f* (which should be rounded to a handsome semi-arc), is the part of contact: the screw, *n*, with the elastic power of the spring, and by bearing at its end against the side of the cock, adjusts for the right distance at the point. This figure is exceedingly simple, and most easy of adoption.

Figure 21.

Now we come to that modification in which it is probable much good will be found. This must be called the grand diameter-bar.† It will be found of easy construction.

Here we have the bar itself, made to do double duty: it is to be regarded no longer as the diameter-line; it will be deprived of a great part of its polarity. It presents to the eye a spherical action, and forms one grand universal compensating power, in connexion with the arcs of the circle. It scarcely requires any definition; the object is at once seen to the now fully informed reader and examiner.

c c c c are the weights; those at the extremities of the arcs of the circle have a double duty, spherical and lateral; both centripetal: the elevated screws affixed on the weights give an increased power in obtaining the object: the very small elevated screws, with their small holes, obtain those nicer portions of time, in finding the adjustment proper: *d d* are the screws for timing: *b b* the rim: *l l* are the abutments, which should be valued much, on account of the very great assistance they render in case of violence; the mechanical form of the abutments is my own introduction: they are seen in the diagram, gracefully declining, and losing thsemelves in the arcs of the circle.

Figure 22,

Is the reverse of Fig. 21.

Figure 23.

This is the interior view in perspective of fig. 21. The attention can be directed to the substance and composition of the diameter-bar cut through the middle, and shows a portion of the hole at *a*: *c c* shows the manner by which the weights are secured on the periphery of the rim, where the screws present themselves: the altitude of the balance is also seen: and at *o o* the line shows where the balance-rim is cut through, to give gentle pressure to the time-screws, as before stated.

* Mr. Airy.

† Its reverse presents a brass superficies. [It appears necessary to state distinctly, that the diameter-bar consists of a double lamina, of brass and steel, united in the same manner as in the ordinary curved compensation-bars.—G. B. A.]

Figure 24,

Is the old plain balance, assisted at *l l* by my improvement of the abutments: *m m* show where it is cut open, to give liberty to the laminæ for compensation, as noticed in past figures.

Figure 25,

Is an interior view of fig. 24. The abutment is seen gradually to lose itself in the rim, or lamina.

Figure 26.

This is a curious, yet easy method, I have introduced in these papers. It is customary to solder for curbs; this method will supersede that difficulty. It will be found very useful, on account of the number it will produce; and I think I need not recommend it, as it will recommend itself. It is formed of bars of steel, $\frac{1}{8}$ of an inch in thickness, fastened by two lateral bars, and subsequently put into the crucible, and compounded with brass, similar to the common method used for compensation balances. It is seen here in a quadrangular form, but, of course, can be made to angle or caliper.

J. S. EIFFE.

APPENDIX.

SPECIFICATION OF A PATENT GRANTED TO MR. ROBERT MOLYNEUX FOR IMPROVEMENTS IN CHRONOMETERS.

To all to whom these presents shall come, I ROBERT MOLYNEUX, of Southampton-row, in the county of Middlesex, chronometer-maker, send greeting.

Whereas HER PRESENT MAJESTY QUEEN VICTORIA, by her Letters Patent, under the great seal of the United Kingdom of Great Britain and Ireland, bearing date at Westminster, the seventh day of March, now last past, did give and grant unto me, the said ROBERT MOLYNEUX, her especial license, full power, sole privilege, and authority, that I, the said ROBERT MOLYNEUX, my executors, administrators, and assigns, or such others as I, the said ROBERT MOLYNEUX, my executors, administrators, or assigns, should at any time agree with, and no others, from time to time, and at all times thereafter, during the term of years therein expressed, should, and lawfully might make, use, exercise, and vend, within England, Wales, and the town of Berwick-upon-Tweed, my invention of an IMPROVEMENT OR IMPROVEMENTS IN CHRONOMETERS; in which said Letters Patent, there is contained a proviso, obliging me, the said ROBERT MOLYNEUX, by an instrument in writing, under my hand and seal, particularly to describe and ascertain the nature of my said invention, and in what manner the same is to be performed, and to cause the same to be enrolled in her said Majesty's High Court of Chancery within six calendar months, next and immediately after the date of the said Letters Patent, as in and by the same, reference being thereunto had, will more fully appear. **Now know ye,** that in compliance with the said proviso, I, the said ROBERT MOLYNEUX, do hereby declare, that the nature of my said invention, and the manner in which the same is to be performed, is particularly described and ascertained as follows, and by the drawings hereunto annexed (in all of which said drawings or figures, similar parts are marked with similar letters). MY INVENTION consists of a certain improvement or improvements in that part of a chronometer usually known by the name of the balance; by means of which I am enabled to obtain a much more complete compensation for the expansion and contraction of the balance-spring, in various changes of temperature, than has hitherto been obtained: and the manner in which I can effect this purpose, will more fully appear by the following description, and drawing annexed:

Figures 1 and 2 represent two views of a compensation-balance, made in the usual manner, to which is attached ONE MODIFICATION OF MY INVENTION of a certain improvement or improvements in chronometers, in which *a a* are the weights, *b b* the timing-screws, *c c* the arm, and *d d* the rim, or lamina, composed in the usual manner, of brass and steel, or other fit and proper metals. To this balance I attach two supplementary compensation-pieces, *e f* and *e f*, each attached (in this my FIRST MODIFICATION) to the inner side of the balance-rim, *d d*, by means of a screw at the end, *f*, the other end, *e*, being free, and furnished with a regulating screw, *g*. In the balance-rim is screwed an adjusting screw, *h*, the point of which acts against each supplementary piece, *e f*, by which the free ends of such pieces are brought nearer or further from the centre of the balance, as may be required. THE ACTION OF THIS MODIFICATION is as follows:—Having in the usual manner compensated the balance, so that its vibrations shall be equal at the temperature of 30° and 55° of Fahrenheit, it will be found, that if it be raised to higher temperatures, such balance will vibrate, so that the chronometer will decrease its rate, or lose its time; but by my invention I am enabled to compensate for this loss in the following way:—In figure 1, the balance, with its supplementary compensating pieces, is shown in the position it assumes at the temperature of 55°, its rim being then considered circular, and the middle projecting portions of the supplementary compensating pieces banked in contact with the inside of the balance-rim. Now, if the temperature be raised, the balance-rim, with the supplementary compensating pieces, will come into the position shown in figure 2, in which, from the increase of heat, the balance-rim has ceased to be circular: its free ends, to which the adjusting screws, *h h*, are attached, having approached nearer the centre of the balance, and with them carried the free ends, *e e*, of the supplementary compensating pieces, so that their middle projecting portions no longer bank, or are in contact with the inner side of the balance-rim; and thus, by a proper adjustment of the length, position, and weight, of the supplementary compensating pieces, I am enabled to compensate for temperatures above that at which the balance has been adjusted; while the adjustment for temperatures of 30° and 55°, to which the balance had been before adjusted, remains unimpaired. MY SECOND MODIFICATION is a supplementary compensation for lower temperatures than that to which the balance has been adjusted in the usual manner, namely, 55° and 80°. An example thereof being shown in the drawing, figures 3 and 4, in which the supplementary compensating pieces, *e f* and *e f*, are attached to the free ends of the balance-rim, *d d*, and their middle projecting portions banking or being in contact with such free ends when at or above the temperature of 55°, as represented in figure 3; while for temperatures below that heat, the free ends of the balance-rim, having receded from the centre, have left the middle and free portions of the supplementary compensating pieces, which, therefore, counteract the decrease of rate or loss of time which otherwise would have taken place, while the adjustment of temperatures of 55° and 80°, to which the balance had been before adjusted, remains unimpaired. A THIRD MODIFICATION of my invention is represented in figure 5, in which I obtain a supplementary compensation to the balance, independent of the action of the balance-rim, as an auxiliary thereto. To the arm, *c c*, I attach the outer arcs of metal, *i j* and *i j*, by the screws, *k* and *k*. To the ends; *i* and *i*, of these arcs, are attached two compound arcs, *l m* and *l m* (made of brass and steel, or other fit and proper metals, similar to those composing the balance-rim), by the screws, *l* and *l*, in such a manner that their opposite extremities, *m* and *m*, shall be free.

To these free ends I fit regulating screws, *n* and *n*, and in the outer arcs are adjusting screws, *o* and *o*, the points of which act against the free ends of the compound arcs. In this modification, the balance is adjusted for high temperatures, similar to the modification shown at figures 1 and 2; the action of the free compound arcs being independent of the rim, and effecting the same purpose as the supplementary compensating pieces represented in those figures. I DO NOT MEAN OR INTEND TO CLAIM AS MY INVENTION any of the parts hereinbefore described or shown in the drawings, which are known or in use, but which it was necessary to introduce and describe for the full and clear understanding thereof. NOR DO I LIMIT OR CONFINE MYSELF to the particular modifications of my invention shown or described, or the materials of which the several parts are composed. BUT I DO CLAIM as my invention of an "IMPROVEMENT OR IMPROVEMENTS IN CHRONOMETERS," a means whereby the compensation for changes of temperature usually adopted in the balance of a chronometer may be made more perfect, by the addition of a supplementary compensation thereto, as represented in the several modifications hereinbefore described, or otherwise. **In witness** whereof, I the said Robert Molyneux have hereunto set my hand and seal, this seventh day of September, in the year of our Lord, One thousand eight hundred and forty.

ROBERT MOLYNEUX.

L.S.

Taken and acknowledged by the said Robert Molyneux, at Croydon, in the county of Surrey, this seventh day of September, One thousand eight hundred and forty, before me,

H. RICHARDS,
A Master Extra in Chancery.

The Engravings require the following small corrections :—

In Plate I., figure 3, the points of the small screws, *g g*, should be represented as projecting through the arms, *e e*, and nearly touching the arms, *b b*.

In Plate III., figure 10, the letter *g* for one of the large screws upon the arm has been omitted.

In Plate IV., figure 22, the shading of the threads of the screws, *d d*, is omitted.

Fig. 1.

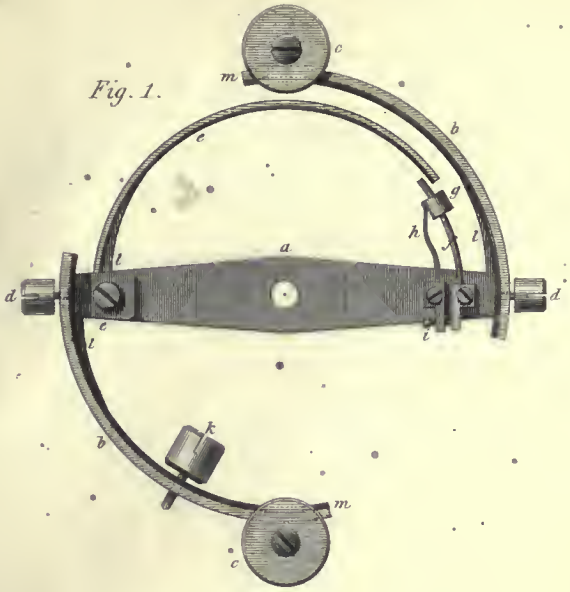


Fig. 2.

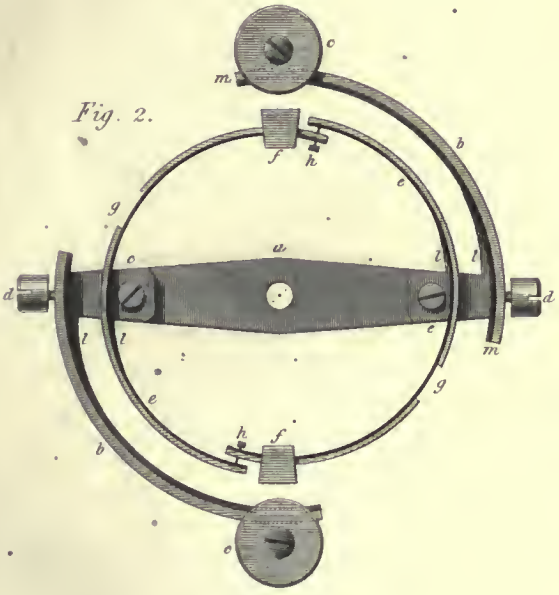


Fig. 6.

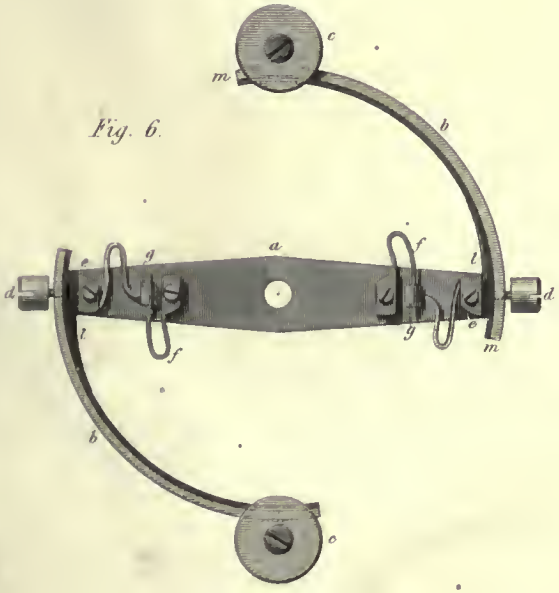


Fig. 3.

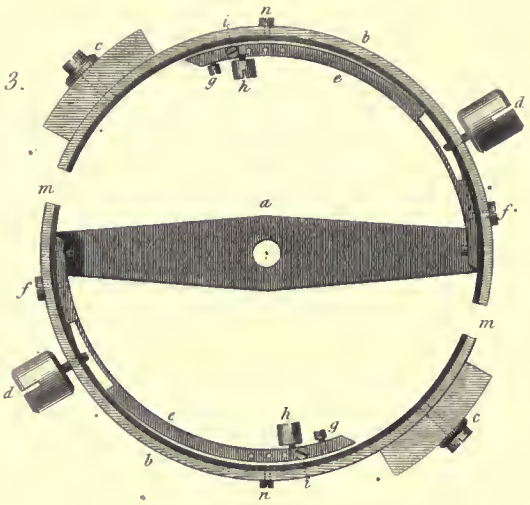


Fig. 4.

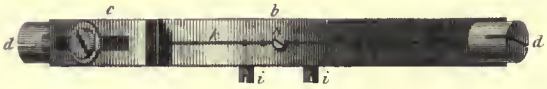


Fig. 5.

Fig. 7.

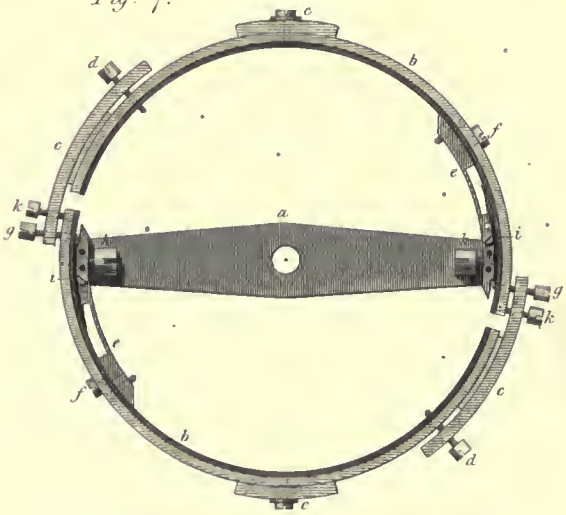


Fig. 8.

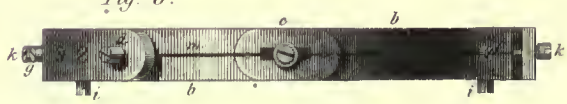
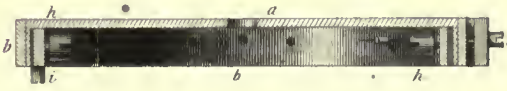


Fig 9.



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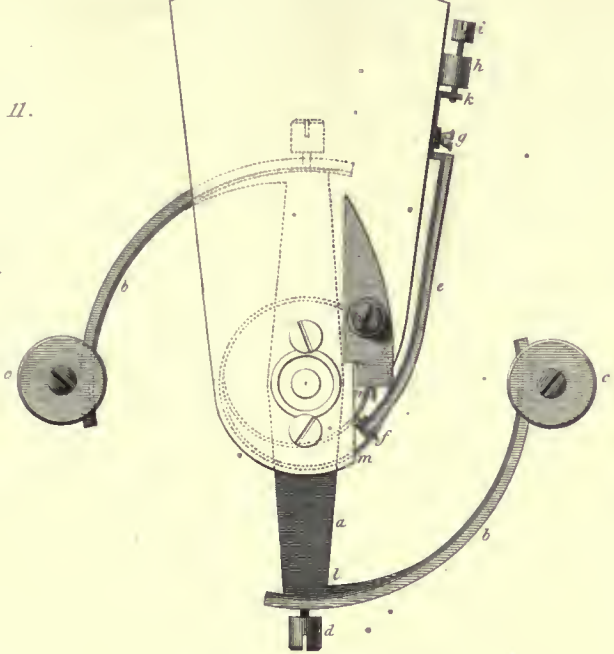

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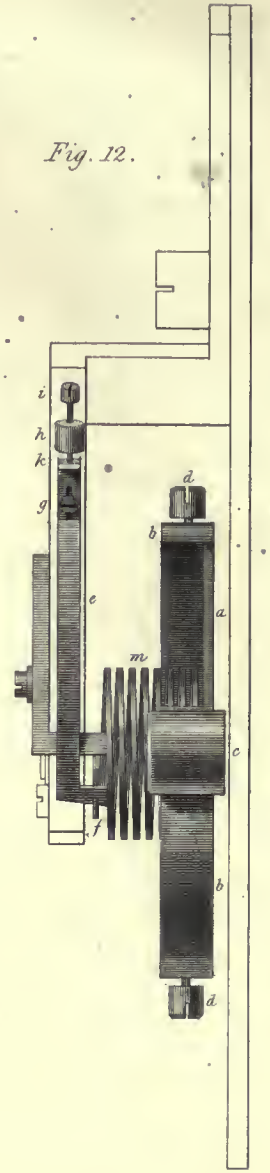

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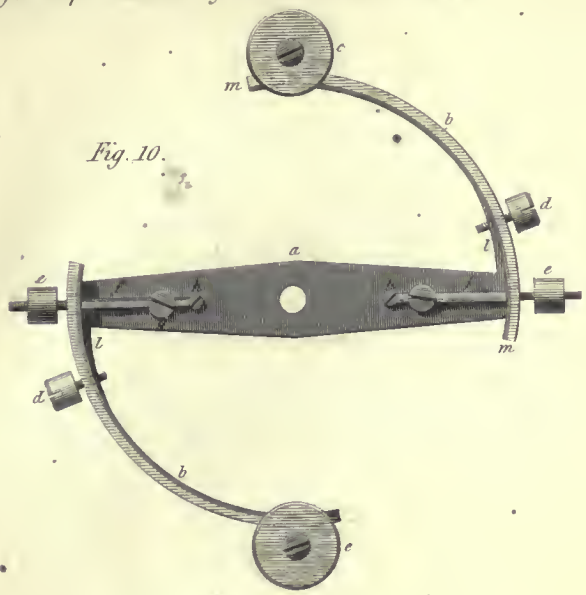

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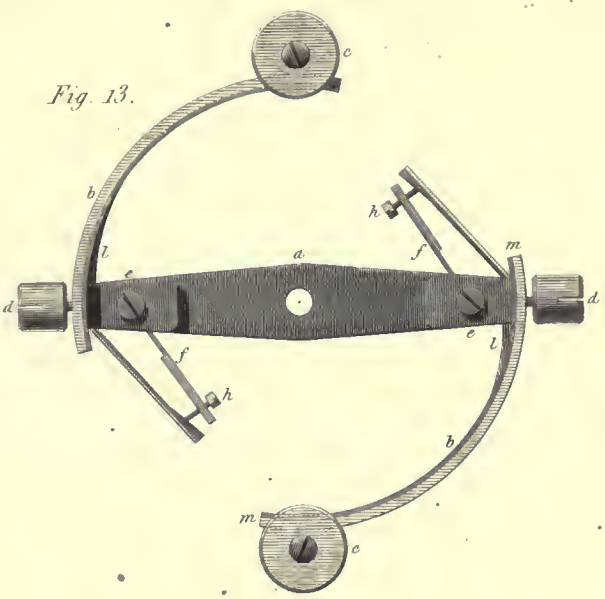

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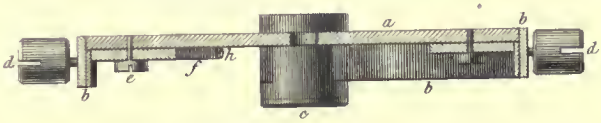

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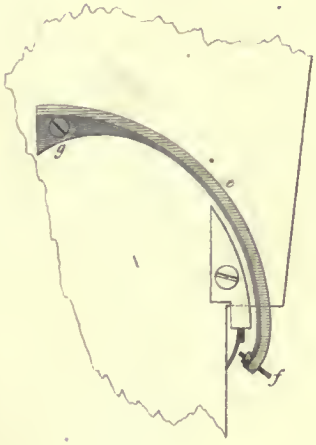

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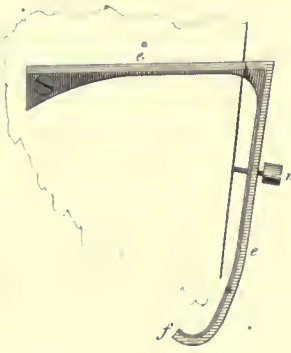
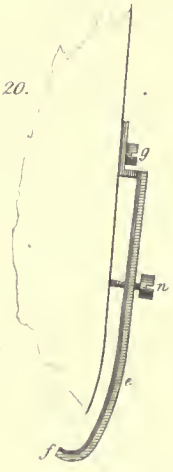


Fig. 18.

Fig. 19

Fig. 20.



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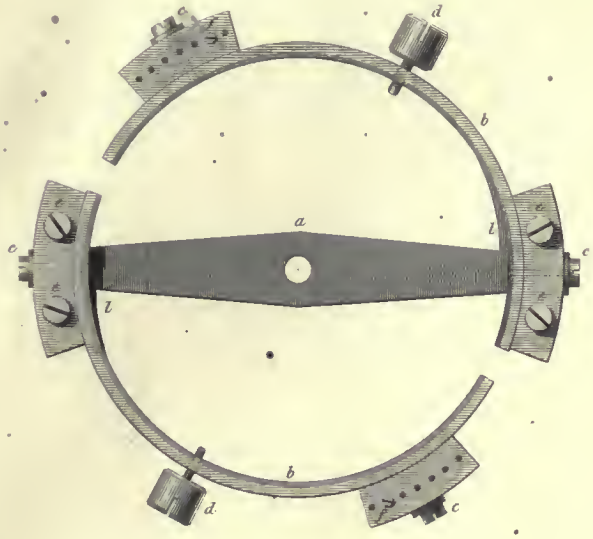

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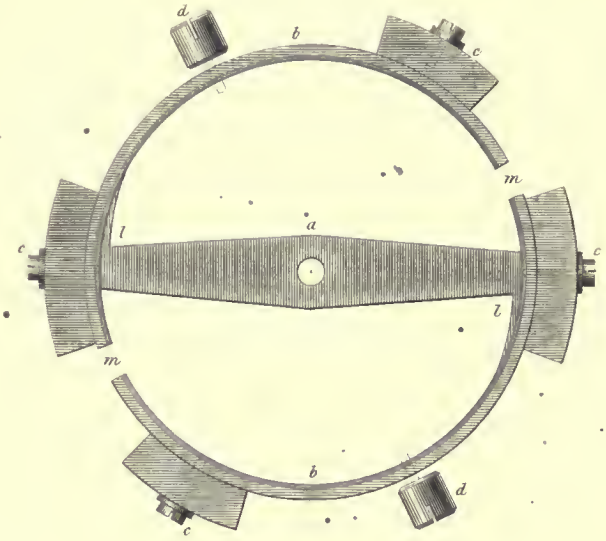

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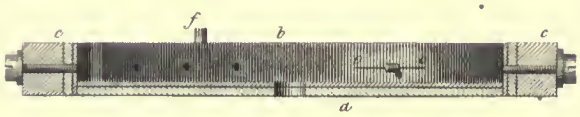

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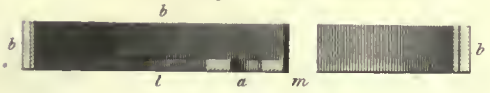

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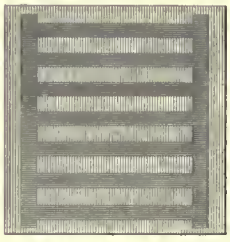

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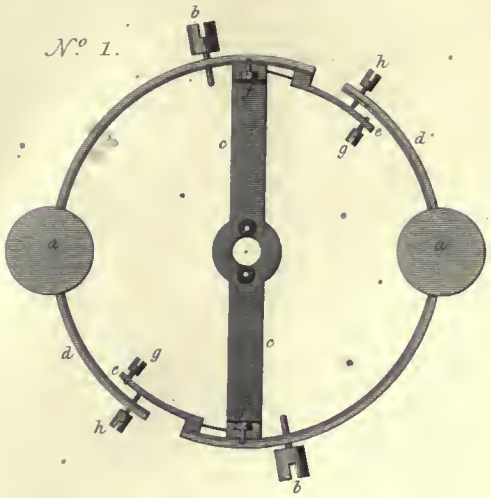

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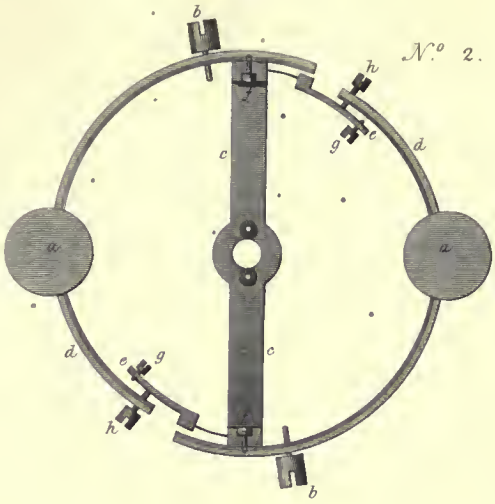

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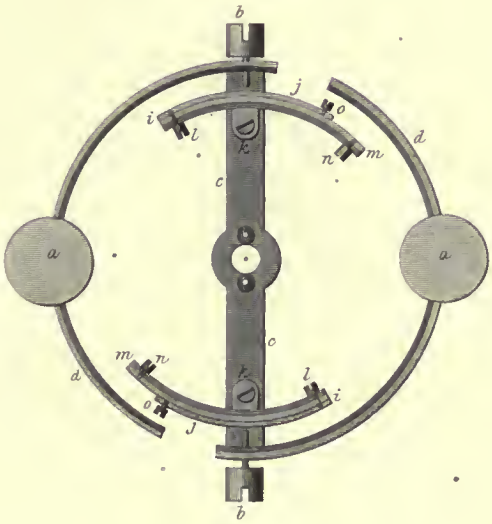

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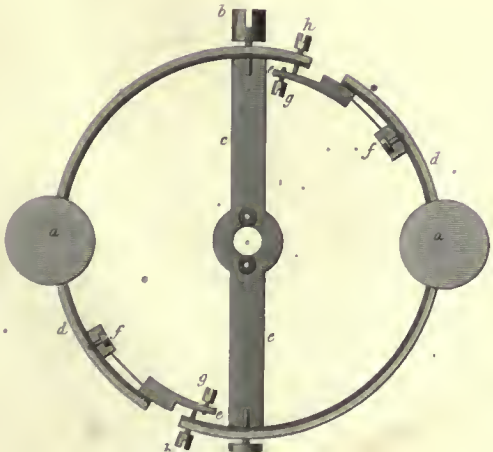

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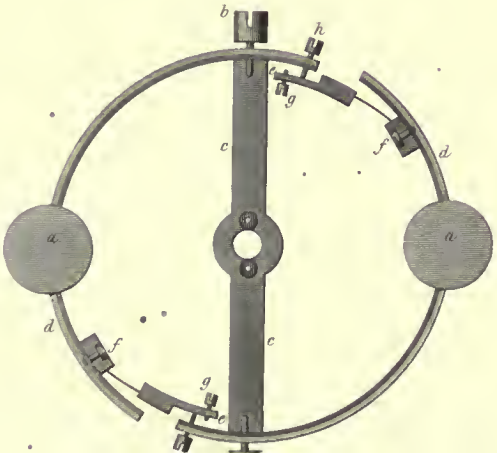

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